Oxygen Extraction from Regolith Using Ionic Liquids

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Introduction

- President's vision for human space exploration includes manned missions to an asteroid by 2025, followed by missions to Mars by the mid-2030's
- Utilizing materials present in space is crucial for these types of mission

Multi-purpose Crew Vehicle

Originally Published by NASA/Lockheed Martin

The Need for Oxygen

- A critical component for propulsion and life support systems
- Abundant in extraterrestrial regolith in the form of metal oxides

Previous Methods of Extraction

- Hydrogen Reduction
  - Low oxygen yield
  - Selective of composition
- Molten Oxide Electrolysis
  - High operating temperature (1600°C)
  - Not selective of composition

Molten Oxide Electrolysis operating at 1600°C

Originally Published by MIT?NASA

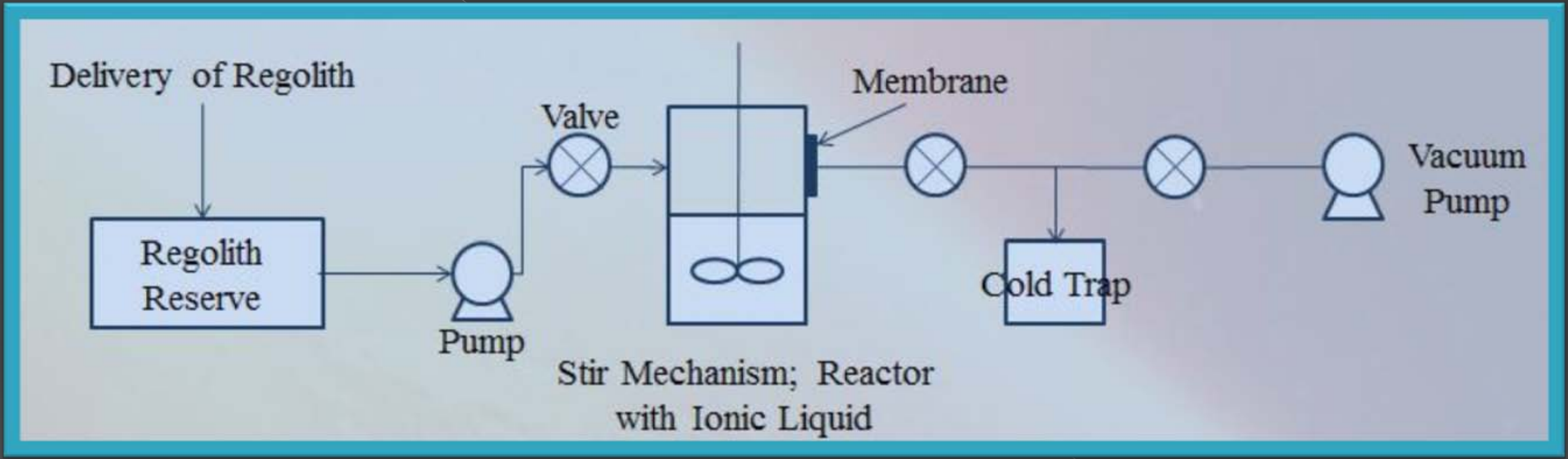
What are Ionic Liquids?

- A liquid composed of oppositely charged ions
- Can be designed for a specific task
- Melts at 100°C or below
- Negligible vapor pressure and low flammability

Why are IL's Attractive for Oxygen Extraction?

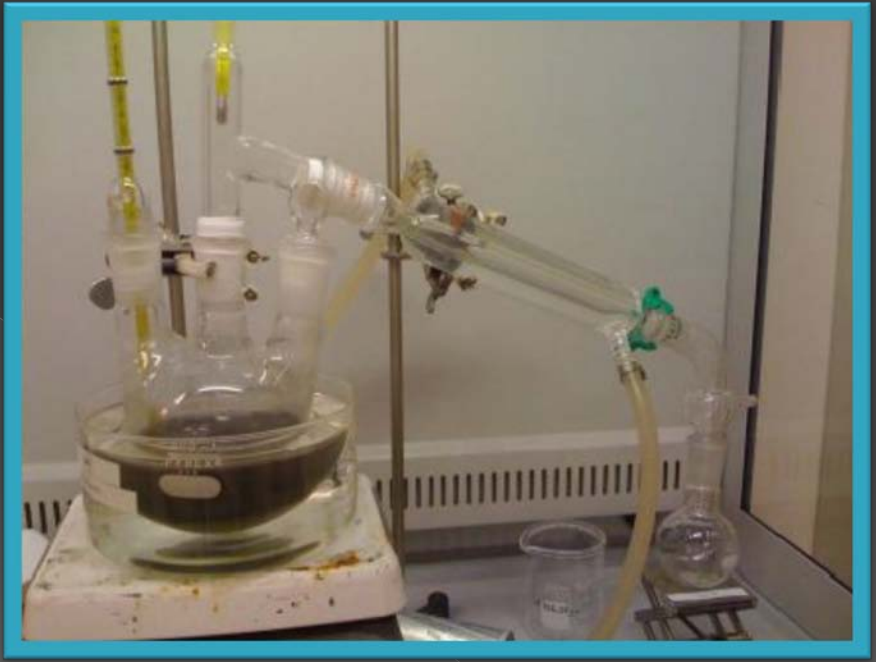
- Lower operation temperature to around 200°C
- Not selective of regolith composition
- Low toxicity
- Ionic liquid can be regenerated and reused

Basic Schematic



Extracting Oxygen using Ionic Liquids

- Solubilize regolith in ionic liquid at 200°C
  - Products: water vapor, spent ionic liquid, metal ions
- Condense water vapor
- Liquid water is electrolyzed in ionic liquid electrolyte to form H_2 and O_2



Laboratory solubilization of lunar regolith simulant, JSC-1.

Mechanisms of Oxygen Extraction

$$(a)\quad Regolith(Metal\ Oxides) + Ionic\ Liquid \rightarrow H_2O_{(v)} + Metal\ Ions$$

$$(b)\quad 2H_2O \xrightarrow[\text{ionic liquid}]{\mathcal{E}} 2H_2 + O_2$$

(a) Solubilization of Regolith into water vapor and metal ions
(b) Electrolysis of water product into hydrogen and oxygen

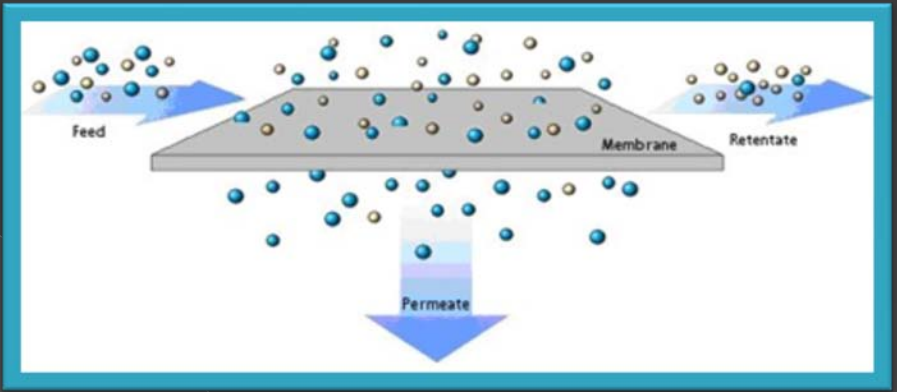
Working in Low-Gravity

- Absence of natural phenomena
  - Buoyancy
  - Sedimentation
- Presence of high vacuum atmosphere
- Problems encountered during oxygen extraction process

The effects of buoyancy on a candle flame. Left picture: Earth; Right picture: low-gravity space

Pervaporation

- Does not rely on buoyancy. Relies on:
  - Selective, porous membrane
  - Different rates of diffusion
  - Applied vacuum across membrane



Basic pervaporation process

Purpose

- To explore the possibility of utilizing and incorporating the method of pervaporation into the existing oxygen extraction process using ionic liquids

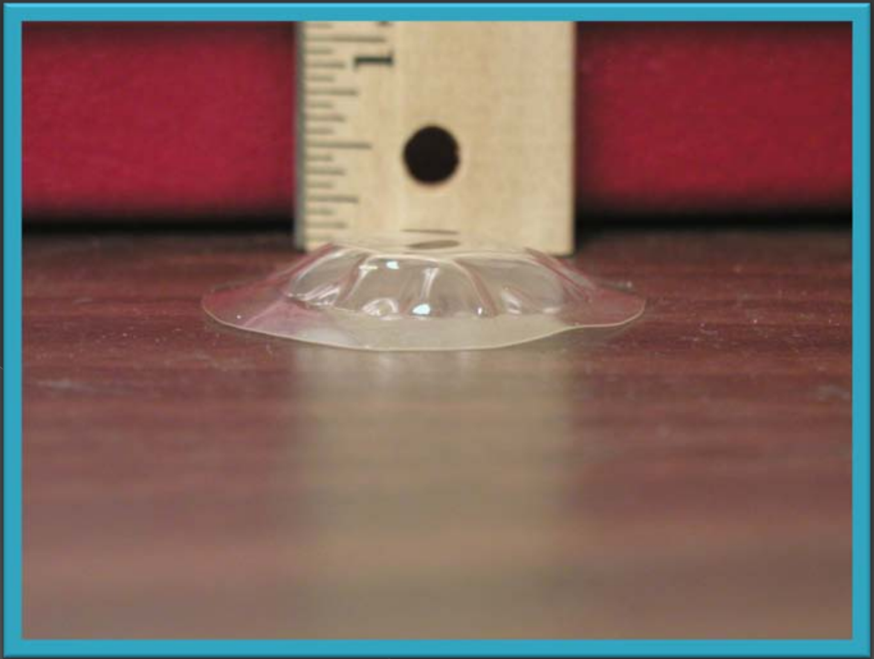
Methods and Materials

- Sulfonated Teflon membrane, thickness 183 μm, contact area = 1017.88mm^2
- 30% aqueous ionic liquid
- Testing:
  - 1 apparatus verification test
  - 2 stirring tests
  - 1 high temperature test
  - 1 long duration test

Testing Apparatus

Verification of Testing Apparatus

- 100 mL distilled H_2O
- 20°C for 4 hours
- Water flux = 1225.8g/m^2hr
- Membrane absorbed 0.0646 g H_2O
  - Needs to be pre-saturated



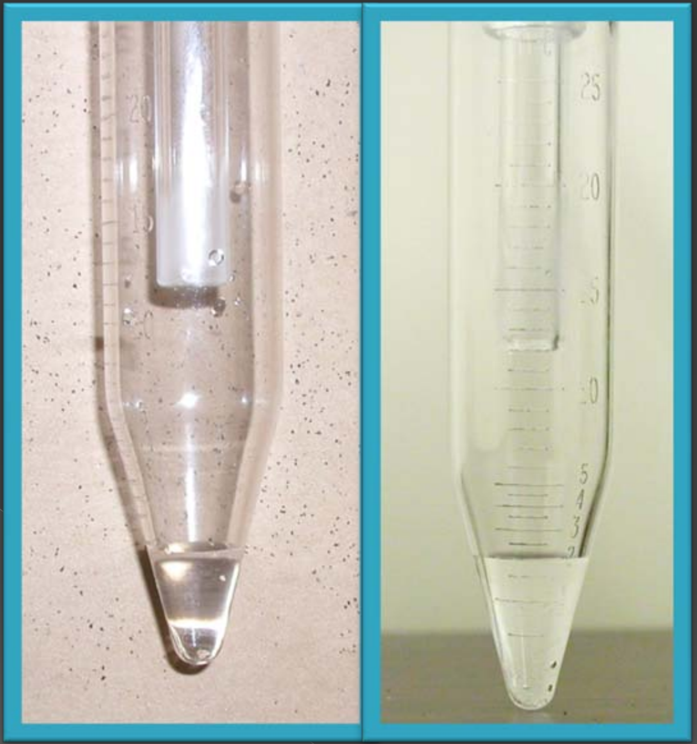
A pre-saturated membrane

Test 1 and Test 2

- Purpose: Determine if a stirring mechanism is needed to obtain proper results
- Both tests ran with
  - 20 mL sample of 30% aq. Ionic liquid
  - Temperature = 20°C
  - Time = 6.5 hours

Test 1 and Test 2 Results

- Test 1 (no stirring)
  - 1 mL H_2O collected
  - Water flux = 150.90g/m^2hr
  - ΔP = -200 mTorr
- Test 2 (stirring)
  - 2 mL H_2O collected
  - Water flux = 301.71g/m^2hr
  - ΔP = +33 mTorr
- Conclusion: need stirring for proper results



(left) Test 1 – 1mL H_2O collected no stirring; (right) Test 2: 2 mL H_2O collected with stirring

Test 3

- Purpose: Determine if the membrane could withstand operating at elevated temperatures while being in contact with the ionic liquid

- Test conditions:
  - 20 mL sample of 30% aq. Ionic liquid
  - Temperature = 50°C
  - Time = 6.5 hours

Test 3 Results

- 3 mL H_2O collected
- Water flux = 452.52g/m^2hr
- Lost approximately 2.5 mL during the process
  - Probably due to evaporation

- Conclusion: Membrane and ionic liquid can operate at elevated temperatures, but need to develop a tighter seal to eliminate evaporation

3 mL H_2O collected

Test 4

- Purpose: Determine if the ionic liquid pervaporation process could withstand operating for extended periods of time.

- Test conditions:
  - 20 mL sample of 30% aq. Ionic liqiud
  - Temperature = 20°C
  - Time = 78.5 hours (3 days, 6.5 hours)

Test 4 Results

- Successfully demonstrated this process works well for extended period of time.
- All water pulled from aq. ionic liquid and pre-saturated membrane (no water flux could be calculated)
- Liquid remaining in funnel was quite viscous (this is the ionic liquid)

The membrane after the water was pulled from it during Test 4

Conclusion

- A sulfonated Teflon membrane could successfully separate water from an ionic liquid
- Stirring is needed to avoid any build up on one side of a membrane
- Membrane can withstand exposure to ionic liquids at elevated temperature and for extended periods of time
- Could be a highly successful replacement for distillation in the low-gravity space environment

Future Research

- Test pervaporation during actual regolith (or simulant) solubilization
- Examine the rest of the oxygen extraction process for issues that may arise during low-gravity operation
- Further develop and refine process schematic so an actual model can be made and deployed into space

Acknowledgements

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Questions?